KERR-McGEE CHEMICAL LLC
POST OFFICE BOX 66 - HENDERSON, NEVADA 89009

January 19, 2001

Ms. Brenda Pohlmann
Nevada Division of Environmental Protection
555 East Washington, Suite 4300
Las Vegas, NV 89101

Dear Ms. Pohlmann:

Subject:Las Vegas Wash Seep Characterization Report

Please find attached a report containing the results of field activities associated with the Kerr-McGee Chemical LLC (Kerr-McGee) "Work Plan for Seep Area Groundwater Characterization", March 22, 2000. Please feel free to call Ed Krish (405) 270-3752 or myself (702) 651-2234, if you have any questions regarding this report. Thank you.

Sincerely,

SMCrowley

Susan M. Crowley
Staff Environmental Specialist

cc:	LKBailey	Doug Zimmerman, NDEP – Carson City
	PSCorbett	Jennifer Carr, NDEP – Carson City
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	TWReed	Rick Simon, ENSR
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	FRStater	

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SEEP AREA GROUNDWATER CHARACTERIZATION REPORT

KERR-McGEE CHEMICAL LLC
HENDERSON NEVADA FACILITY

Prepared by
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8000 West Lake Mead Drive
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January 18, 2001

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SUMMARY

Kerr-McGee Chemical LLC (KMCLLC) is committed to developing and implementing a workable remediation technology to capture and destroy perchlorate entering Las Vegas Wash from its industrial plant in Henderson, Nevada. Because implementation of this remediation strategy involves removal and treatment of perchlorate-bearing water from both the Seep and the Pittman Lateral area it is important to understand the hydrogeological conditions operating in this area. Of primary concern is how the City of Henderson-Rapid Infiltration Basin (COH-RIB) affects the groundwater volume and perchlorate concentration in the Seep and the underlying aquifer. Equally important is the concern of whether or not additional significant perchlorate is entering Las Vegas Wash at other locations. The scope of the present investigation was to answer these concerns. The specific objectives were to:

- determine the hydrogeologic regime in the area between the Pittman Lateral and the Seep,
- determine the representative perchlorate concentration in the saturated thickness of the alluvial aquifer near the Seep,
- determine if any additional pathways exist along Las Vegas Wash for other significant perchlorate contribution,
- determine the rate of movement and the residence time for perchlorate and groundwater between the Pittman Lateral and the Seep and,
- determine potential groundwater pumping strategies.

The results of this investigation indicate that:

- The BMI Lower Ponds area, encompassing the Seep, is the only identified area of groundwater discharge containing significant perchlorate entering Las Vegas Wash.
- In the Lower Ponds area the main north-northeast trending alluvial paleochannel coalesces with a second poorly-defined paleochannel entering the area from the southwest, the perchlorate concentration of which has yet to be determined.
- In the Lower Ponds area, where the two paleochannels coalesce, the entire saturated interval of the alluvial aquifer contains perchlorate >10 mg/l over a width of about 2200 feet.

- The COH-RIB facility contributes huge amounts of treated wastewater at random times for random lengths of time and directly contributes to daylighting of groundwater in the Lower Ponds area and to wide fluctuations in both the flow volume and perchlorate content of the Seep.

- The rate of movement for groundwater and perchlorate between the Pittman Lateral and the Seep averages 35 ft/d and the residence time is about 6 months.

- Pumping of groundwater in the Lower Ponds area would only be a short-term solution. It will be more efficient to pump from the Pittman Lateral area.

Based on the results of this investigation it is recommended that KMCLLC continue to design and plan to build a groundwater capture system near the Pittman Lateral to partly feed the planned IX-Catalytic Destruction plant to be built on the KMCLLC plant facility. It is further recommended that additional drilling and monitor well installation be completed to better define the location and groundwater chemistry of the western paleochannel and that annual sampling and mapping be conducted to monitor any changes in the extent and concentration of the perchlorate and conductivity plumes north of Sunset Road and along Las Vegas Wash.

1.0 GENERAL GEOLOGY AND HYDROLOGY

The regional study area is located in the southeast portion of the Las Vegas Valley within the city limits of Henderson, Nevada. The Las Vegas Valley occupies a topographic and structural basin lying within the Basin and Range physiographic province. The valley is wide, flat, and slopes southeasterly from an elevation of about 2,000 feet above sea level at Las Vegas to about 1,200 feet at Lake Mead. Mountains composed of igneous and sedimentary rocks rise steeply along the borders of the valley and coalescing alluvial fans slope gently from the mountains toward the valley floor. The Las Vegas shear zone cuts diagonally northwest-southeast across Las Vegas Wash 2 miles east of the Seep area. Las Vegas Wash, a shallow, narrow stream that flows southeasterly across the valley, drains into Lake Mead.

The study area is underlain by the Miocene Muddy Creek formation. The Muddy Creek is a valley-fill deposit and has a wide range of lithologies including coarse-grained sands and gravels near the mountain fronts along the south portion of the study area and fine-grained silts and clays toward Las Vegas Wash. Lacustrine gypsiferous clays and silts have been intersected in drill holes in the vicinity of Las Vegas Wash and crop out in an old gravel pit on the east side of the study area. Not all geologists accept that this fine-grained sequence is the Muddy Creek formation and would prefer to equate it to the Pleistocene Chimihuavi formation of the Colorado River valley. Until known interbedded volcanic deposits are age-dated this question will remain unresolved.

Younger Quaternary alluvial deposits rest unconformably on the Muddy Creek formation. The lithology of these alluvial sediments is a heterogeneous, well-graded mixture of sand and gravel with lesser amounts of silt, clay and caliche. Boulders and cobbles are common. Generally, the coarsest-grained alluvial sediments thin and pinch out from south to north toward Las Vegas Wash. These deposits fill erosional paleochannels in the Muddy Creek formation and thin laterally over the interfluvial areas. Paleochannels generally trend northeast-southwest and control the movement of shallow alluvial groundwater. Their linearity may be fracture controlled. Depth to water in these alluvial deposits ranges from near-surface close to the Wash to more than 30 feet on the KMCLLC plantsite. Horizontal hydraulic groundwater gradients are in the range of 0.001 feet per foot (ft/ft) to 0.04 ft/ft and average about 0.017 ft/ft. Closer to the Wash, water levels in wells indicate that hydraulic head is higher in the Muddy Creek formation than in the alluvial deposits with vertical gradient directed upward. Chemical composition of the water is generally a sodium chloride-sulfate type and is classified as slightly to moderately saline.

2.0 SEEP CHARACTERIZATION INVESTIGATION OBJECTIVES

In the March 22, 2000 KMCLLC *Work Plan for Seep Area Groundwater Characterization* and in a NDEP letter dated October 9, 2000 (Pohlmann to Crowley) objectives were to:

- Provide additional information about the physical and chemical characterization of the Seep area groundwater,
- Delineate the perchlorate plume and identify where it enters Las Vegas Wash,
- Determine whether any additional sources of perchlorate exist along the Wash, and
- Provide an analysis of potential short-term options for immediate groundwater treatment in the Seep area.

These objectives were accomplished through:

- Installation of a series of nested monitor wells along an east-west traverse between the Seep and the Lower Ponds,
- Sampling groundwater in the Las Vegas Wash from the Silver Bowl stadium, down stream 4 linear miles, to about 0.75 miles west of the upper dam of Lake Las Vegas,
- Regional sampling of groundwater in monitor wells from the KMCLLC plantsite to the Seep and mapping of physical and chemical perameters,

- Completion of a series of tracer tests to determine the residence time of groundwater and perchlorate between the Pittman Lateral and the Seep area,

- Completion of mapping to determine whether additional seeps are contributing to the perchlorate impact in Las Vegas Wash, and

- Evaluation of groundwater pumping strategies.

3.0 FIELD INVESTIGATION PROCEDURES

Fieldwork for this investigation began during the week of March 6, 2000 and continued through several phases of drilling and sampling until completion during the third week of September 2000. Field work included reconnaissance mapping and sampling of groundwater seeps and springs along Las Vegas Wash, drilling soil borings, installing monitor wells, sampling groundwater from monitor wells, installing and monitoring dataloggers at the 3 tracer test sites, conducting pump tests and tracer tests and surveying the drill locations. Borings and monitor wells were drilled and installed by Compliance Drilling of Las Vegas whereas wells used for tracer tests were drilled and installed by Layne Christensen Company of Chandler, Arizona. Groundwater analyses were performed by the KMCLLC Henderson facility and by Montgomery-Watson Laboratory in Pasadena, California. NEL Laboratories, Las Vegas, performed bromide analyses associated with the tracer tests.

3.1 SOIL BORINGS

A total of 27 soil borings were drilled during this investigation. The placement of 20 of them was within 8 groups of 2 to 3 holes each. The boring locations, designated PC-74 through PC-102, are shown on Figure 1 and Plates 1-5. These holes were drilled using either a 10.5- or 8-inch outside diameter hollow stem auger (HSA) for monitor wells or a 9-inch outside diameter duel-wall reverse-air-circulation percussion hammer for tracer test wells. A split barrel sampler, measuring 2-inchs wide by 1.5-feet long was used to collect soil samples at key intervals during drilling activity to accurately log changes in subsurface lithology. Both soil samples from the split spoon sampler and cuttings from the drilling activity were examined for lithologic type and logged in accordance with the Unified Soil Classification System (ASTM D-2488). All field lithologic information was recorded on soil boring log forms, which are included in Appendix A. All boreholes, not completed as permanent monitor wells, were sealed with cement grout. Hole locations were staked and labeled for subsequent surveying.

3.2 MONITOR WELL INSTALLATION

Twenty-one groundwater monitor and 5 tracer test wells were installed during the investigation program. All except 2 wells were constructed using 2-inch diameter screwthreaded Schedule 40 PVC casing and 0.020-inch factory-slotted screen and installed through the HSA or the percussion hammer assembly. The other 2 wells, used as tracer introduction wells, were constructed using 4-inch PVC and 0.040 screen. The bottom of the well screen section was fitted with a 0.2-foot long bottom plug. The entire annulus surrounding the screen was filled with clean, 8-12 size washed sand to about 3 feet above the top of the screen. An annular seal of bentonite pellets was placed above the filter pack sand to a thickness of 2 to 3 feet. The remaining well annulus from the top of the bentonite seal to the surface was filled with a Portland cement/bentonite grout. After the annular seal was hydrated and allowed to set, the wells were developed with a submersible Grundfos pump until sediment-free water was achieved.

In order to sample discrete intervals of the lower, middle and upper parts of the saturated alluvial aquifer along an east-west traverse in the Lower Ponds area, the wells were placed in 8 groups with 2 to 3 closely-spaced wells each. Horizontal separation of the borings was 10 feet whereas vertical separation of the screened interval was also 10 feet.

Surface completion of all wells was below grade using flush-mounted steel manhole covers set in concrete pads. Locking well caps were utilized for security. Well construction diagrams are included in Appendix B.

3.3 GROUNDWATER SAMPLING

Groundwater samples were collected for laboratory perchlorate analysis during the soil boring phase of the investigation and again following monitor and tracer well installation. All analytical results are included in Appendix C.

3.3.1 Soil Borings

Because most of the soil borings were to be made into nested monitor wells, only 5 groundwater samples were collected from the borings during drilling. These samples were collected through the augers either at the total depth of the boring or at the time the water table was encountered. PVC bailers were used for the sampling and were decontaminated with Alconox and bottled water prior to each use. The samples were analyzed at the KMCLLC facility laboratory for perchlorate and conductivity.

3.3.2 Monitor and Tracer Test Wells

Groundwater samples were collected from 238 existing and new monitor wells and tracer test wells in the regional study area. These samples were analyzed for perchlorate and conductivity at the KMC LLC facility laboratory.

3.3.3 Las Vegas Wash Seeps and Springs

Twenty-two samples of daylighting groundwater from seeps, springs and shallow hand-dug pits were collected along a 4-mile long traverse from the Silver Bowl stadium to within 0.75 miles of the upper dam of Lake Las Vegas. These samples were analyzed for perchlorate and conductivity at the KMCLLC facility laboratory and/or Montgomery Watson in Pasadena.

3.4 ALLUVIAL PUMP TESTS

In preparation for tracer test studies, Errol L. Montgomery & Associates, Inc., Tucson, Arizona conducted 2 pump tests in August 2000 in the tracer introduction wells at tracer test sites B (City of Henderson-Rapid Infiltration Basin) and C (Lower Ponds). Since tracer test site A was sited at the Pittman Lateral to make use of an existing, previously pump-tested, well (PC-70) as a tracer introduction well, no new pump test was performed.

Construction and development of the new 4-inch tracer introduction wells was by Layne Christensen Company, Chandler, Arizona. The test pump was installed and operated by Compliance Drilling, Las Vegas, Nevada. The constant-discharge pumping tests were preceded by a short pretest and step-discharge test to verify equipment operation and to select an optimal pumping rate for testing. Aquifer tests were planned for 36 hours of pumping followed by 36 hours of water level recovery. Due to a generator failure, duration of pumping was 29.9 hours for well PC-98R (Site B). For Site A, a 48-hour constant-discharge pumping test was conducted in well PC-70 in September 1998 by Kerr-McGee personnel (Kerr-McGee, 1998).

The details of the PC-70 (Site A) pump-test are presented in Attachment 1 whereas the procedures used for the Sites B and C tests are detailed in a December 19, 2000 report by Errol L. Montgomery and Associates which is presented in Attachment 2.

3.5 TRACER TESTS

Since analysis of the rate of groundwater movement can be used to estimate the rate of mass transport of perchlorate in groundwater, Errol L. Montgomery & Associates, Inc. conducted tracer studies at 3 locations between the Pittman Lateral and the Seep shown in Figure 1 and Plates 1-5. Tracer testing, conducted in September 2000, consisted of natural gradient and drift and pumpback methods using deionized water and bromide as the tracers. Deionized water was made at the Kerr-McGee Apex facility and supplied to the test sites via stainless steel tanker truck. Volumes of deionized water used for the tests ranged from 1,800 gallons at Site A to 2,630 gallons at Site C. Specific conductivity of the injected water was 5 microSiemens/cm. At each site, pairs of wells between 30 and 40 feet apart were drilled and constructed for tracer introduction and downgradient tracer breakthrough observation. Tests lasted for a minimum of 4 hours to a maximum of 1.9 days.

For bromide tracer tests at Sites A and C, bagged solid calcium bromide was mixed in a tanker truck with reverse osmosis water supplied from the Kerr-McGee Henderson facility. The bromide solution was introduced into the wells via a flexible hose which was moved up and down to distribute the solution evenly throughout the well. Immediately following the bromide introduction a conductivity probe was inserted in the well and a vertical conductivity profile was obtained which showed relatively uniform distribution.

At Site A the bromide solution was mixed to yield a concentration of about 3200 mg/l and introduced into well PC-70 containing about 1 mg/l bromide as background. Sampling of groundwater in observation well PC-101R at depths of 23, 32 and 40 feet was conducted using a peristaltic pump and a micro-purge method. In the drift and pumpback test in PC-99R (Site C) a bromide solution similar in strength and composition to the bromide test at Site A was introduced into the well and distributed vertically to get a relatively uniform distribution. Previously determined aquifer parameters were entered into a formula which determined the drift time of the introduced bromide slug, the duration of pumpback time and the frequency for sample collection for bromide analyses. Sampling frequency ranged from 5 minutes per sample during the first part of the test to 15 minutes for the later part. Bromide samples were analyzed at NEL Laboratories, Las Vegas, Nevada.

3.6 COORDINATE AND ELEVATION SURVEY

All soil borings and wells were surveyed for vertical elevation control and horizontal location using a Trimble 4800 survey-grade Global Positioning System (GPS) unit. The survey used existing HARN points and first order benchmarks in the southern Las Vegas Valley to establish an overall control grid for the study area. Monitor and tracer wells were surveyed for TOC elevation, ground elevation and horizontal control whereas soil borings were surveyed for ground elevation and horizontal control.

Locations of the Las Vegas Wash seep/spring/pit samples were either surveyed for horizontal location by Southern Nevada Water Authority (SNWA) personnel using a Trimble Pro-XRS sub-meter (GPS) unit or by digitizing from a high-quality aerial photograph. All survey data are presented in Appendix D.

4.0 FIELD INVESTIGATION RESULTS

This section details the results of the Las Vegas Wash groundwater sampling, drilling, monitor well sampling and analyses, pump test activities and tracer test studies conducted as part of this investigation.

4.1 ALLUVIAL HYDROGEOLOGIC CHARACTERIZATION

Figure 1, the base map of the regional study area, shows the locations of both historic and newly installed monitor wells. New KMCLLC wells are part of the PC-series starting with PC-74 and are located mostly in the Lower Ponds area south and west of the Seep in sections 31 and 36. With only 1 exception all borings were drilled into the underlying Muddy Creek formation and all wells were screened only in the alluvium. Except for the tracer test wells, which were fully screened, all nested-wells sets were installed with 5 or 10-foot screens in order to incrementally sample the lower, middle and upper parts of the alluvial aquifer. Boreholes within nests are 10 feet apart and screened intervals are also 10 feet apart to insure no cross-communication. Lithologic logs for the new borings are presented in Appendix A and well construction diagrams are presented in Appendix B.

4.1.1 Groundwater Flow Conditions

In May 2000 a cooperative regional groundwater sampling event between KMCLLC and American Pacific Corporation (AMPAC) resulted in the sampling of 238 alluvial groundwater monitor wells for water levels, perchlorate and conductivity concentrations. Plate 1, the Potentiometric Surface Map of the Quaternary Alluvium Aquifer, shows the results of this sampling and the location of Plates 2 through 5. This mapping is an update of mapping completed in July 1998 by KMCLLC (Kerr-McGee Chemical LLC, 1998a). Data points for Plate 1 are listed in Appendix C.

Groundwater in the Quaternary alluvium represents the shallow water table in the central and northern portions of the map area. Water flow is generally north-northeast with minor variations. As was the case with the July 1998 mapping, the average horizontal hydraulic gradient between the KMC LLC facility and Las Vegas Wash remains about 0.017. The gradient from south to north is seen to be fairly uniform except in the major north-northeast alluvial channel beneath the northern part of the industrial site (SW 1 and NE 11, T22S R62E) and beneath the City of Henderson Rapid Infiltration Basin (COH-RIB) in section 36. Here, the infiltration of treated wastewater into the alluvial aquifer from the RIBs has caused a mounding of groundwater with a resultant decrease in the hydraulic gradient in the potentiometric surface.

Continuing long-term monitoring of depth to groundwater since July 2000 is being accomplished at all 3 tracer sites through the use of In-Situ, Inc. "Troll 8000" and "Mini-Troll" dataloggers. Figure 4 shows the results of groundwater monitoring in well PC-101 at Site A, upgradient of the RIBs, between September 9th through November 20th. Pumping in adjacent well PC-70 accounts for the small drawdown events seen on September 12th and October 6th. Water levels are seen to be steady to very slowly rising through about October 14th when several rain events were recorded over a several week period. Discounting the data from October 30th to November 14th as probably invalid due datalogger malfunction, the water level in this area continued to slowly rise to a little less than 16 feet below surface through to November 20th when the datalogger permanently malfunctioned. The importance of this graph is in its comparison to the water level changes at Site B (COH-RIB) and Site C (Lower Ponds/Seep).

Figure 5, the graph from tracer test Site B, shows the changes in depth to groundwater (DTW) and conductivity for the 5.5-month period from July 7th to December 26th. That the infiltration of COH-RIB wastewater into the shallow aquifer results in wildly erratic water levels is amply illustrated. The small blip on the DTW and conductivity graphs on July 10-11 is from the pump test in adjacent well PC-98R whereas that on September 13th is from the tracer test. The figure shows that a massive recharge event, starting on September 12th raised the groundwater level from about 13.5 feet to 4.5 feet in about 3 weeks. Since about October 27th the water level has been decreasing. It is obvious from this graph that even forewarned by a schedule of flooding events from COH, trying to model groundwater flow and predict perchlorate mass flow to the Seep and the underlying alluvial aquifer would be futile. Unless a capture and treatment system was dramatically oversized versus average flows, it could not predictably capture and treat the constantly changing water and perchlorate volume entering the Wash.

Figure 6, the datalogger depth-to-water graph for well PC-99 at Site C, shows that, starting about August 9th – eight days after the start of infiltration at the RIBs, the water level began to rise dramatically. The level continued to rise until October 6th when it became relatively static. The drawdown event on August 13-14 is the pump test of adjacent well PC-99R. It is interesting to note that the width of the graph line is due to the diurnal effect presumably of salt cedar evapotranspiration or, as seen starting on about September 23rd, simple evaporation. On about October 31st ground flooding at Site C necessitated abandoning the site and moving the datalogger 400 feet to the west to PC-87. Figure 7 shows that the water level in PC-87, which held relatively constant since October 31st, started to increase again on December 15th. It is no coincidence that the slough just north of the Lower Ponds began flowing again in late July-early August and that widespread daylighting of groundwater has been occurring in the adjacent areas since late September-early October when COH started filling the RIBs with wastewater.

As part of the temporary Ion Exchange (IX) Plant record keeping, KMC LLC personnel monitor the throughput of the plant and the calculated perchlorate mass flow rate and the Seep stream perchlorate concentration. Figure 8 show that since April 4th these data have fluctuated widely based on a combination of natural and man-made conditions. As seen by comparing this graph with the graph of depth to water in the COH-RIB, Figure 5, most of the increase in stream flow since August 12th, and culminating in a flow of 593 gpm on October 14th, is directly due to water from the RIBs. It is interesting to note that the highest Seep stream perchlorate concentration, 120 mg/l on October 16th, occurred during this high flow and has been decreasing ever since. A possible explanation is that the lower density RIB water temporarily displaced the higher density perchlorate-bearing water and pushed it ahead to the Seep.

As of January 9, 2001 the Seep stream flow and perchlorate concentration were 416 gpm and 49 mg/l, respectively, whereas the perchlorate mass flow rate was 245 lbs/day. Since the temporary IX Plant is rated at about 450 gpm it would be possible to pump groundwater to the plant during the low-flow summer period from about May to October or longer, depending on the amount of water infiltration from the COH-RIBs. In the 280 days since the temporary IX plant began operation, the stream flow has averaged 315 gpm and there has only been 31 days with stream flow over 450 gpm. However, as of now, KMC LLC does not have a permit to discharge treated groundwater. This topic will be revisited in a later section.

4.1.2 Alluvial Channel System

The Quaternary alluvial channel system contains the thicker portions of saturated alluvium in the study area. These channels typically act as preferred pathways for groundwater flow, especially groundwater that contains higher TDS and higher densities. Plate 2 shows the contoured thickness of the shallow alluvial aquifer north of Sunset Road. The trace of the main north-northeast channel is particularly prominent on this map. Also shown is evidence for a poorly-defined sub-parallel western channel, at least 40 feet thick, running diagonally across the central part of section 36. The recently completed nested-wells along the northern boundary of sections 31 and 36 substantially refined the subsurface geology in this area. As shown in Figure 2, a 1"=200' east-west hydrogeologic cross-section, the mouth of the western channel is deeper than the mouth of the main eastern channel. It is here, where the two channels coalesce, that the groundwater perchlorate values exceed 10 mg/l over a width of about 2200 feet. Figure 3, the cross-section across the Pittman Lateral is an update of a cross-section presented in a July 1998 report (Kerr-McGee Chemical LLC, 1998). Its scale is 1"=400', the same scale as Plates 2 through 5, and it shows the highly incised nature of the main alluvial channel as well as recent water level conditions and perchlorate concentrations.

The erosional nature of the alluvial channel system into the underlying lithologic unit is apparent on Plate 3, the structure map on top of the Muddy Creek formation. Mapping shows the deep incision of the channel beneath the Pittman Lateral and the poorly defined sub-parallel channel diagonally crossing the center of section 36.

The cross section (Figure 2) also shows an old Stauffer exploration hole, HSC-2, located in the extreme SW corner of section 30. What is interesting about this hole is the lithologic description of massive beds of gypsum and anhydrite below 100 feet. (structural elevation of about 1458 ft). The closest highly gypsiferous beds are in section 32, 1.5 miles to the southeast which lie at structural elevations 100-200 feet higher. These lacustrine evaporite units are probably equivalent. Two tiny seeps in the gypsum beds in the center of section 32 were found to contain up to 28 mg/l perchlorate. A potentiometric surface map of this area made in 1997 shows that groundwater flow in the fine-grained Muddy Creek formation comes from the south-southeast. Only the extreme eastern end of the Upper Ponds is upgradient of these seeps. However, since recent seep sampling found only perchlorate values up to 2.5 mg/l directly downgradient of the main part of the Upper Ponds, the high concentrations in the tiny seeps are probably not coming from the ponds. Furthermore, the alluvium directly upgradient from the high perchlorate seeps is dry. Naturally occurring perchlorate is found associated with evaporates in Chile and this occurrence may be of a similar nature. Regardless, there is currently no evidence that this perchlorate is entering Las Vegas Wash.

4.1.3 Well Pump Tests

Constant-discharge pumping tests were conducted in August 2000 at tracer test Sites B and C to obtain aquifer properties. A pumping test of PC-70 (Site A) was previously performed in September 1998. Results of these aquifer tests show that transmissivity ranges from 50,000 gallons per day per foot (gpd/ft) for site A (Pittman Lateral) to 160,000 gpd/ft at Site C (Lower Ponds/Seep). Hydraulic conductivity ranges from about 1,700 gallons per day per square foot of aquifer (gpd/ft^2) at Site A to 4,600 gpd/ft^2 at Site C. A summary of the aquifer parameters from these three tests is shown in Table 1 below:

TABLE 1

Site	Pumping Rate (gpm)	Transmissivity (gpd/ft)	Aquifer Thickness (feet)	Hydraulic Conductivity (gpd/ft2)
A	45	50,000	30	1,700
B	52	60,000	25	2,200
C	65	160,000	32	4,600

That the transmissivity and hydraulic conductivity is higher in the north end of the area is not surprising given the history of the Lower Ponds. The ponds were constructed in 1943 within highly permeable alluvial sands and gravels. During the next 30 to 40 years the ponds were used as infiltration basins for industrial discharge water. This constant use over such a long period of time guaranteed that whatever fines were originally deposited with the coarse-grained sediments were washed out of the deposits. In the 1970's seepage from the Lower Ponds was reported to be as high as 1500 gpm (Kaufmann, 1978).

4.1.4 Tracer Tests

Rate of groundwater movement provides a good estimate for the rate of mass transport of perchlorate since it is considered a nonreactive ion and should flow at the same rate as the groundwater. Rate of groundwater movement was measured at Site A at the Pittman Lateral, Site B in COH-RIBs and Site C in the Lower Ponds/Seep area. Two methodologies were used – natural gradient and drift and pumpback – with bromide and deionized water used as tracers. Tracer test locations are shown on Figure 1 and Plates 1-5. The procedures used for these tests are detailed in a December 19, 2000 report by Errol L. Montgomery and Associates which is presented in Attachment 2.

The results of tracer testing using deionized water under natural gradient conditions indicated rate of groundwater movement to be about 20 to 25 ft/d at Site A, 45 ft/d at

Site B and 85 ft/d at Site C. Prior to testing it was expected to record tracer breakthrough as the decrease in specific conductivity in the downgradient observation well because, at 5 microSiemens/cm, the deionized water was 3 to 4 orders of magnitude lower than the conductivity of the ambient groundwater. However, tracer breakthrough was seen at Sites A and C as an increase in the conductivity above background, followed by a decrease to pretest levels as the slug of tracer water moved past the observation well. This phenomenon is thought to be the result of changes in the chemistry of the dissolved ions in the groundwater caused by ionic exchange, differences in ionic strength of the solution and differences in pH of the solution due to the addition of the diluting stream. Nevertheless the data could be used to determine groundwater velocities. At Site B the natural gradient test using deionized water yielded a curve that showed a decrease of conductivity as the slug of tracer water went past the observation well. The rapid filling of the nearby RIBs during the test complicated the interpretation of the results.

Calcium bromide was used as a tracer under natural gradient conditions at Site A and under drift and pumpback conditions at Site C. At Site A, samples were collected from depths of 23, 32 and 40 feet in the observation well 30 feet downgradient, to check for differences in breakthrough times at different depths. The results show that breakthrough in the lower part of the aquifer was slightly faster than breakthrough in the upper part. Assuming symmetrical breakthrough and peak concentration represents the center of mass of the bromide slug, travel time between the introduction and observation well pair ranges from 21.5 to 25.2 hours. Rate of groundwater movement is estimated to be about 30 ft/d. At Site C the 4,200 mg/l bromide brine tracer was injected into PC-99R in a manner similar to PC-70. After injection, a conductivity probe determined that a relatively uniform vertical distribution of bromide was achieved. After 2 hours of drift, pumping began and sampling from the pump discharge continued for the next 4 hours. The results show that the center of mass of the bromide pulse was recovered after about 30 minutes of pumping. Subsequent calculations indicate that the rate of groundwater movement is about 60 ft/d and the effective porosity is about 10 percent.

Based on lithologic data obtained from well installation, aquifer test results and tracer test results, a summation of the rate of groundwater movement is presented in Table 2 below:

TABLE 2

Site	Natural Gradient - Deionized Water Tracer Tests (ft/d)	Natural Gradient - Bromide Tracer Tests (ft/d)	Drift and Pumpback - Bromide Tracer Test (ft/d)	Natural Gradient - Darcy's Law (ft/d) Porosity = 10%
A	25-30	30	no test	20
B	45	no test	no test	30
C	85	no test	60	65

Using Darcy's Law and average values for aquifer parameters and groundwater gradient, the minimum estimate of groundwater movement between Site A, Pittman Lateral and Site C, the Lower Ponds/Seep, is 35 ft/d. Based on the distance of 5,700 feet between Pittman Lateral and the Seep the average residence time for perchlorate to move from the Lateral to the Wash is about 6 months.

4.2 GROUNDWATER CHEMICAL CHARACTERIZATION

Groundwater samples were collected as part of this investigation from daylighting seeps, springs and shallow hand-dug pits along Las Vegas Wash and monitor wells between the KMCLLC plant site and the Seep and analyzed for perchlorate and specific conductivity. These analytical results were used to map the extent and concentration of the perchlorate and high conductivity groundwater plumes in the shallow alluvial aquifer and along the banks of Las Vegas Wash. Laboratory analyses of perchlorate and specific conductivity are attached in Appendix C.

4.2.1 Chemical Characterization of Groundwater Along Las Vegas Wash

As part of this investigation reconnaissance mapping and groundwater sampling were conducted along Las Vegas Wash in March and April 2000. Using water samples collected from 22 naturally-occurring seeps, springs and shallow hand-dug pits, the downgradient variation of perchlorate and conductivity was recorded along 4 linear miles of Duck Creek and Las Vegas Wash (LVW) from the Silver Dome eastward.

Results show that even though perchlorate is detected in groundwater throughout the entire length of the survey, the only significant groundwater contribution of perchlorate occurs in the vicinity of the Lower Ponds/Seep area. This is the location where KMCLLC is currently removing perchlorate from surfacing groundwater.

The accompanying color aerial photograph, Figure 9, of a portion of Las Vegas Wash shows the locations of the sample sites used in this survey. Below each sample number is the perchlorate value in ug/l and the field conductivity value in uSm/cm. In the broadest terms the geochemical makeup of the wash can be divided into the following three stretches:

Western Stretch: This zone, between sample KM89 on the west and KM56 on the east, is characterized by low to non-detect perchlorate and moderate to high conductivity. Locations KM68 through KM58, containing between 8000 to 10400 uSm/cm, sampled a plume of highly conductive shallow groundwater flowing into Duck Creek and LVW from the southwest. The low conductivity in sample KM59 may reflect dilution from surface water since it was collected from a dug pit whereas the other three samples are from natural seeps. East of KM58, locations KM57 and KM56 continue to show low perchlorate levels. Conductivity levels also decrease.

Central Stretch: This part of LVW occupies the area between KM71 on the west and KM53 on the east. Samples from the western one-third of this reach contain the highest perchlorate concentrations found anywhere along LVW. Between KM56 and KM55 the perchlorate level in groundwater increases from ND to 57000 ug/l, decreasing again to 4500 ug/l. As shown on the aerial photograph this zone of high perchlorate is directly north and east of the mapped outlet of the north-northeast trending paleochannel and the Lower Ponds/Seep area.

However, because the perchlorate footprint in this part of the wash is so wide it has long been suspected that an additional source of perchlorate is joining the groundwater flow into the wash from the western end of the Lower Ponds. Alluvial thickness mapping indeed found a separate sub-parallel northeast-trending channel coalescing with the main channel just south of the seep. Any perchlorate in this western channel could not have come from the KMCLLC plant site and may have come from the former AMPAC site. However this has yet to be proven.

East of KM55, and continuing all the way to KM53, the photograph shows that both the perchlorate and conductivity levels of groundwater flowing into the wash decrease to the 290 to 400 ug/l and 2500 to 3500 uSm/cm range, respectively. This water quality indicates a cleaner groundwater inflow than found either to the west or the east.

Eastern Stretch: Beginning at KM91, both the perchlorate and conductivity levels increase again to a maximum of 3000 ug/l and 7400 uSm/cm, respectively. These high values occur at sample site KM65, a natural seep located in a fault zone that is part of the Las Vegas Shear Zone. This area has been named the Calico Hills Water Gap (CHWG), the place where Tertiary bedrock is first exposed in the bottom of the Wash. This thinning has the effect of causing the laterally-inflowing groundwater and the sub-wash groundwater, and their contained perchlorate inventory, to rise to the surface at this location. East of this Water Gap the sediments filling the Las Vegas Wash valley remain relatively thin over the uplifted bedrock.

Because KM65 and KM91 to the west, are samples of the rising sub-wash groundwater, it is important to note that these values (2100 to 3000 ug/l) are probably representative of the average perchlorate concentration in storage between the Seep at the Lower Ponds and the CHWG.

The next two samples east of the CHWG are relatively low in perchlorate whereas the third sample, KM67, increases again to 2100 ug/l. These low perchlorate samples are probably due to dilution with groundwater inflowing from adjacent cleaner sources. The higher perchlorate value in the easternmost sample is probably due to communication with the higher perchlorate in the sub-Wash groundwater in another fault zone.

The results of this groundwater sampling program show that the only significant perchlorate source entering the Wash is the known Seep area north of the Lower Ponds. Slightly elevated perchlorate values found east of the Calico Hills Water Gap are the result of surfacing groundwater from the sub-wash storage and not a new source of perchlorate.

4.2.2 Chemical Characterization of the Alluvial Groundwater in the Seep Area

Plates 4 and 5 show the groundwater perchlorate and conductivity plumes north of Sunset Road, respectively. As shown on Plate 4, perchlorate concentrations up to 490 mg/l occur in the main alluvial channel at Sunset Road. Northward, perchlorate content decreases to about 320 mg/l in the COH-RIB area and 150 mg/l or less near the Seep. The two east-west cross sections along the Pittman Lateral (Figure 3) and the Lower Ponds (Figure 2) show the relationship of channel geometry and water chemistry. At the Pittman Lateral perchlorate values >10 mg/l extend eastward 800 feet from the main channel whereas in the Lower Ponds area high perchlorate values extend westward over a width of about 1800 feet from the main channel. The perchlorate isopach map also shows some evidence that perchlorate-bearing groundwater, thought to be the alluvial plume from the former AMPAC plant, may be entering the Seep area from the western sub-parallel channel. AMPAC's perchlorate plume in the Muddy Creek formation has not as yet been identified entering the Wash. Both the map and cross section show that the highest perchlorate values in the total saturated zone occur in nested wells PC-85, 86 and 87 between the two coalescing channels.

Vertical profiling of wells north of the COH-RIB in January 2000 shows that the treated wastewater from the RIBs does not appreciably mix but floats on the underlying denser groundwater. This is shown in the cross section (Figure 2) and the conductivity map (Plate 5) where relatively lower perchlorate and conductivity values occur in the upper part of the aquifer east of the alluvial channel from PC-56 to PC-97. Comparison of the conductivity map with the perchlorate map shows that the trend of conductivity highs, up to 17170 uSm/cm, lies parallel to and west of the main alluvial channel and highest perchlorate concentrations. A second plume of high conductivity may occupy the western northeast-trending channel but has not yet been proven.

5.0 ANALYSIS OF SHORT-TERM GROUNDWATER OPTIONS

The current long-term remedy calls for the construction of an 825 gpm IX-Catalytic Destruction plant to destroy perchlorate on the KMCLLC plantsite. Flow of 400 gpm and 360 gpm, respectively, will come from a proposed well field at the Pittman Lateral and the Seep stream with the remainder coming from the plantsite. At the present time the KMCLLC discharge permit does not allow treatment and release of groundwater from the Seep or the Pittman Lateral area.

The current temporary IX plant operating at the Seep stream can handle a nominal 450 gpm. The Seep stream has been seen to fluctuate in the last year from about 225 gpm in the summer season to about 640 gpm in the winter season. The flow volume in the Seep stream depends, in large part, on the volume of wastewater dumped into the RIBs by COH and evapotranspiration by the vegetation. Since April 4th the stream flow has averaged 315 gpm and only been above 450 gpm for 31 out of 280 days.

The question has been raised by NDEP regarding the ability of the existing temporary IX system to process more water. The answer depends on the actions taken by COH. As long as the Seep stream flow is below 450 gpm the IX plant is not being fully utilized and groundwater could, in theory, be processed. The answer is equivocal because a method for organics destruction must first be in place, the discharge permit must be modified and the pumping wells and pipeline must first be installed.

Increasing the temporary IX plant capacity would require 4-6 months to install new pumps, piping and resin beds. Considering that the planned 825 gpm system will be on-line by the end of 2001, it makes little sense to divert resources and manpower away from the major construction effort to install a second temporary system for only a few months use.

Recovering the perchlorate stream at the Pittman Lateral, where the plume is known to be narrower and higher in concentration would ultimately make a more significant contribution to the perchlorate remediation effort. If, as the tracer tests indicate, the residence time between the Pittman Lateral and the Seep is only 6 months, perchlorate groundwater recovery at the Lateral would quickly form a brightline, the movement of which could be readily measured.

6.0 CONCLUSIONS AND RECOMMENDATIONS

Based on the results of the groundwater-sampling program, borehole drilling, lithologic studies, nested-well installation, datalogger monitoring, pump and tracer testing the following data have been added to the body of knowledge regarding the characterization of the perchlorate plume from the KMCLLC plant site to the Wash:

- From the pump and tracer tests it is now known that the rate of movement of groundwater and perchlorate from the Pittman Lateral to the Wash averages about 35 ft/d and the residence time is therefore about 6 months.

- From continuous datalogger monitoring at the three tracer test sites since July it is now known that when the City of Henderson adds millions of gallons of water to the RIBs it has an almost immediate, drastic and unpredictable effect to the water volume, water level and water chemistry in the Lower Ponds/Seep area and the feed to the temporary IX plant.

- From the groundwater sampling program along Las Vegas Wash it is now known that the bulk of perchlorate enters the Wash at the Lower Ponds/Seep area. The 2-3 mg/l of perchlorate sampled at the Calico Hills Water Gap is likely the average concentration of the sub-Wash perchlorate inventory upgradient from the Water Gap.

- From the additional soil borings in the Lower Ponds area, better control of alluvial thickness and Muddy Creek structure shows the existence of a poorly-defined second alluvial channel which adds some unknown quantity of perchlorate, quite possibly from the alluvial plume from the former AMPAC plant, to the Seep area.

- From the nested well installation in the Lower Ponds area it is now known that the entire saturated thickness of the alluvial aquifer is anomalous in perchlorate for a width of about 2200 feet.

- From regional groundwater sampling and updated potentiometric surface, conductivity and perchlorate concentration maps, a better appreciation for the extent and concentration of the perchlorate and conductivity plumes and the hydraulic gradient from the plant to the Wash is now possible.

Based on the results of this investigation the following five recommendations are made:

- Design and build a groundwater capture system near the Pittman Lateral to partly feed the planned IX-Catalytic Destruction plant to be built on the KMCLLC plant facility.

- Drill a series of boreholes in the poorly-defined alluvial channel in the center of section 36 to delineate the channel and incorporate the new alluvial thickness and Muddy Creek structural data into the maps.

- Install wells in some of these holes to monitor for perchlorate and conductivity.

- Annually sample groundwater in all available monitor wells from the KMCLLC plant to the Seep and analyze for perchlorate and conductivity. Construct up-to-date maps of the plumes using these data.

- Annually sample groundwater seep locations along Las Vegas Wash and monitor changes of perchlorate and conductivity concentrations.

7.0 REFERENCES

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